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Access to The Far-UV Universe

Final Report for Contract NAS5-32619

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Abstract

This report summarizes the work performed for the program titled "Access to the Far-UV Universe: Three Far-UV Mission Data Sets" which was supported by the NASA Astrophysics Data Program (ADP). The work was completed over a two-year period starting in July, 1994. The primary goal was to make the Far-Ultraviolet spectral data from the Copernicus satellite project readily available to the astronomical community. A two-year follow-on task was recently awarded with work scheduled to begin this month.

1 Introduction

The third Orbiting Astronomical Observatory satellite, otherwise known as Copernicus, was launched by NASA in August, 1972. The satellite contained a 32-inch reflecting telescope and a high resolution ultraviolet spectrometer system, designed and operated by the Princeton University Observatory until February, 1981. The instrumentation included six photomultiplier tubes designated as U1, V1, U2, V2, U3, and V3. All together, 551 different objects were observed at wavelengths ranging from 900 to 3000 Angstroms. More than 687,000 individual scans were obtained with most scans covering a wavelength region of a few Angstroms. In addition to the raw data sets, the project produced spectral atlases for six particular stars with continuous wavelength coverage from 900 to roughly 1500 Angstroms.

The complete set of Copernicus spectral scans and spectral atlas files were stored in a project-specific tape file format and delivered to the National Space Science Data Center (NSSDC). As part of the approved ADP program (for which George Sonneborn was the principal investigator), LASP personnel developed software to convert the raw tape files to disk files using the Flexible Image Transfer System (FITS) file format.

Work under this task included the following activities:

- evaluate the newly created raw data FITS files and Copernicus spectral atlas files and make necessary format changes,
- create a catalog of Copernicus observations,

- develop software to coadd the U1 scans extracted from the raw data files for the eventual production processing of quick-look coadded data sets,
- develop IDL software to assist users in the analysis of Copernicus data sets,
- scan important Copernicus documents for online access by users,
- make data and documentation accessible to the astronomical community.

2 Raw Data Sets

The raw data sets were formatted using the FITS binary table extension and the recently proposed variable length array facility. (Because Copernicus spectral scans can vary in length, fixed length vectors were felt to be impractical.) Each file contains all the available scans (stored chronologically) for a given target, with each row of the binary table representing data for one particular scan. Task members tested the file format using various FITS readers, and compared the extracted data to tabular data provided by Ron Polidan, one of the original scientific investigators from the Copernicus project. As a result of the testing, several modifications were found necessary to the original raw data sets. In most cases, the problems were due to errors in converting the tape files to FITS disk files. The types of problems discovered included:

- improperly scaled background vectors,
- missing scans,
- missing data points,
- incorrect FITS keyword values,
- improperly formatted FITS keyword entries,
- mis-identified data entries, and
- incorrect FITS file formats.

It was also discovered that the original Copernicus wavelengths were defined in the reference frame of the target. To make the data more generally useful, it was decided that the wavelengths should be converted to a heliocentric reference frame. Except for excluding a few FITS keywords added from the Yale Bright Star Catalog, this was the only change in content made to the original Copernicus raw data sets.

The corrected raw files and spectral atlas files were transferred to the IUE World Wide Web server (i.e., node IUEWWW) and made available to users via both http on the World Wide Web, and an anonymous ftp account.

3 Catalog of Copernicus Observations

Once the raw data files were corrected, programs were written to create a catalog of Copernicus observations. The catalog entries were derived from the FITS primary header keywords stored in the raw data sets. In this manner, the catalog can be easily updated if or when the data sets need to be revised. A few additional fields were added to the catalog including, galactic coordinates, IUE object classifications, and coordinates in both decimal degrees, hr, min, sec, and epochs 1950 and year 2000.

The resulting database files can be accessed using either the standard IDL database routines (i.e, using DBOPEN, DBFIND,...), or using the program CLOG which was specifically written for searching the Copernicus catalog. CLOG also uses the IUEDAC database table ALIAS so aliases for the object names can be specified. In addition, a subset of the catalog fields were transferred to an Ingres database table on IUEWWW and will eventually be searchable via HTML forms by WEB users.

4 Coadded Quick Look Data Sets

Copernicus investigators originally used a program called STACK to coadd scans taken close in time in order to improve the signal-to-noise ratio. STACK however was written for producing one coadded spectrum at a time. In order to produce coadded scans in a production mode, a new routine was written called PSTACK. PSTACK runs efficiently by relying on listing files which contain the row numbers for all the U1 scans for a particular file, and which group the scans according to observation time, wavelength coverage, and whether the scans were affected by stray light (i.e., it is not desirable to coadd uncontaminated scans with those affected by stray light). Using these files, PSTACK extracts the appropriate scans and generates coadded files in FITS format without any additional user-interaction.

Although the above software was completed, decisions still need to be made regarding what additional information should be stored in the FITS header. For example, it is likely that the headers will contain a list of the precautionary comments associated with the individual scans. The coadded quick-look files will be generated, and made available to users, in the follow-on task.

5 Data Analysis Software

Several IDL programs were written to assist users in the analysis of Copernicus data, most of which were built upon the existing IUE Data Analysis Center (IUEDAC) routines. The new programs follow the IUEDAC adopted coding practices and were written to run under VMS, UNIX, MAC and WINDOWS 3.1 operating systems. All disk locations for example, are referenced using user-defined IDL system variables, and spawns to system commands have been avoided. A summary of these programs is given below.

STKPLT.PRO - Plots scan number vs wavelength for data contained in the scan listing files,

SUBLIST.PRO - Reads listing files using various search criteria, displays results, and writes results to a new listing file,

PSTACK.PRO - Production processing version of the coadding routine,

USTACK.PRO - New users version of PSTACK,

STACK.PRO - Subtracts backgrounds and coadds Copernicus scans,

BTABLE.PRO - Displays background counts for a particular orbit,

STK_READ.PRO - Program used by STACK to read listing files,

SETWGT.PRO - Program used by STACK to discard bad points,

CLOG.PRO - Searches the Copernicus database as specified by the user and displays results,

ALIAS.PRO - Searches the alias database (subroutine of CLOG),

CHKERR.PRO - Displays error numbers for a given file and scan numbers,

COMM.PRO - Displays the error code for a given error number.

The IUEDAC routines called by the programs listed above, have been stored in a separate directory so users can download the software without having to install the entire IUEDAC library. The entire set of programs are accessible on node IUEWWW.

6 Support and Distribution

Task members have assisted several users in the analysis and interpretation of Copernicus data. Since a two year follow-on task was awarded, task members will continue to assist users in this manner. Task members will also continue to support the Copernicus WEB page and make the software, databases, and documentation available to users. The data sets, documentation, and catalog have also been made available to NSSDC.

7 Documentation

The following documents have been prepared. Individual program documentation is stored within the prolog of the individual routines.

copreport.tex This document.

readme.txt Introduction to a sample Copernicus data analysis session.

intro_users.txt Introduction to Copernicus data and information on remote access to data and software using the OAO3 account on node FORNAX,

coplog.html HTML file describing the contents of the Copernicus observation catalog.

Guest Investigators Guide The original Copernicus investigators guide, written by the Copernicus Observatory staff, converted to ASCII text files, and reformatted as HTML files for access via the WEB,

Final Operations Report The final project report, prepared by Princeton University, which has been scanned and will eventually be converted to ASCII text,

Spectral Atlas Descriptions HTML-formatted files describing the contents of the Copernicus spectral atlas files.

Reference List A SIMBAD search of published COPERNICUS papers, reformatted as an HTML document.

Poster papers on the development and status of the Copernicus archive were presented at the October, 1995 Astronomical Data Analysis Software and Systems Conference in Tucson, Arizona, and the January, 1996 American Astronomical Society meeting in San Antonio, Texas.

destruction and non-equilibrium heating will be presented. The effects of the strength and hardness of the radiation field on the dust as a function of spectral type and distance from the star will be explored. This work was performed while S. J. Carey held a National Research Council - AFGL Research Associateship.

15.03

An Investigation of the Far-Infrared Emission of the Galaxy with DIRBE

S.L. Snaith (Agnes Scott College/WIRO), D.R. Ciardi, R.R. Thompson (U. Wyoming/WIRO)

We present a study of the diffuse infrared emission of the local interstellar medium for the region $42^\circ \leq l \leq 146^\circ$ and $10^\circ \leq b \leq 50^\circ$. The study was performed using the DIRBE 90° elongation data at 60 μm , 100 μm , 140 μm and 240 μm . We have used a simple cosecant law for zodiacal emission removal and have calculated the mean flux density ratios for the six colors. It is found that the $I_{60-I_{100}}$, $I_{60-I_{140}}$ and $I_{60-I_{240}}$ flux density ratios deviate from the mean flux density ratios as a function of galactic longitude by an average of 36%, 50%, and 58%, respectively. The $I_{100-I_{140}}$, $I_{100-I_{240}}$ and $I_{140-I_{240}}$ ratios show a similar but weaker longitude dependence. This indicates that the smaller grains ($a < 0.01 \mu\text{m}$) in the diffuse interstellar medium have a more variable population density than the population density of the larger grains.

15.04

Far-UV Scattering Characteristics of Galactic Dust Derived from a New Analysis of FAUST Observations

B. Friedmann, A.N. Witt (U. Toledo), T. Sasseen (SSL, UC Berkeley)

In March 1992, the Far-Ultraviolet Space Telescope (FAUST) was used to obtain measurements of the intensity of the diffuse sky background at intermediate and high galactic latitudes (Bowyer *et al.* 1993 ApJ, 415, 875; Sasseen & Deharveng 1995 ApJ, in press). A large fraction of the total detected background was found to be of galactic origin, resulting from scattering by interstellar dust. We have used a new Monte-Carlo radiative transfer model, representing a cloudy galaxy with a realistic radiation field based on the observed locations and UV fluxes for some 58,000 stars, to severely constrain possible values for the dust albedo and the scattering phase function of dust grains present in the diffuse interstellar medium. The observed correlations of the measured background intensity with $\text{cosec } |b|$, $N(\text{H I})$, and the IRAS 100 μm galactic background provided semi-independent constraints for the model. The best solution, which is based on the combined analysis of 14 separate 4° by 4° fields, and which applies to the effective wavelength of 1600 Å, yields most likely values for the dust albedo $a = 0.43 \pm 0.05$, the phase function asymmetry $g = 0.68 \pm 0.10$, and the sum of average airglow and extragalactic background of 700 ± 50 photons $\text{cm}^{-2} \text{s}^{-1} \text{Å}^{-1} \text{sr}^{-1}$. A separate constraint on the extragalactic background alone was not possible in this analysis. While the phase function asymmetry found in this study of diffuse dust is in very close agreement with that observed in dense reflection nebulae and star forming regions, the UV dust albedo in the diffuse medium appears to be about 50% lower than that found in dense clouds.

15.05

An Electronic Archive of Copernicus UV Data in FITS Format

G. Sonneborn (NASA/GSFC), M. Carini, R. Thompson (CSC/IUE Obs), D.A. Klinglesmith (NASA/GSFC)

In 1993 a Copernicus archive project began in the Laboratory for Astronomy and Solar Physics at GSFC, supported by the NASA Astrophysics Data Program, to create an electronic archive of raw and processed ultraviolet spectra from the Copernicus mission and make them available through the World Wide Web. The third Orbiting Astronomical Observatory (Copernicus) was launched in 1972 carrying a Princeton University UV spec-

trograph which obtained high ($\sim 0.05 \text{Å}$) and low ($\sim 0.2 \text{Å}$) resolution spectra in the wavelength region $\sim 900 - 3200 \text{Å}$. Copernicus observed 553 targets (primarily bright stars) between 1972 and 1981, generating 687,718 spectral scans. 254 MB of data were archived by Princeton at NSSDC on 9-track tapes in a mission-unique format.

As part of this ADP program, we have recovered the Copernicus raw spectral scans and reformatted them as disk files using FITS format. Each file contains all observations for a given target, with data pertaining to each spectral scan stored as a row in a Binary Table extension. These files are available through the Copernicus archive WWW site. The Princeton data processing pipeline has been recreated at GSFC and is undergoing tests. "Stacked" (co-added) high-resolution U1 scans ($\sim 930 - 1450 \text{Å}$) produced by this software will be available in the near future. A capability is also planned to enable interested astronomers to stack scans themselves (highly recommended) via remote X-window sessions.

The URL for the Copernicus archive World Wide Web site is <http://iuewww.gsfc.nasa.gov/copernicus/ao3.html>.

15.06

X-ray Shadows of Infrared Cirrus and the Local Hot Interstellar Medium

Q. Daniel Wang (Northwestern U.)

The Sun is located in a region which is filled largely with low-density, X-ray-emitting gas. However, how far this region extends is not yet clear, and basic properties of the hot gas, such as the temperature, is still poorly constrained.

A powerful technique to probe the hot gas is to examine x-ray absorptions (shadows) produced by cool gas clouds whose distances can be determined. We are conducting a systematic study of x-ray shadows in the 0.1-0.3 range. This study consists of three major steps: (1) a search for the shadows cast by infrared cirrus clouds, using the ROSAT and IRAS archives; (2) multi-energy band measurements of local and distant x-ray intensities relative to the clouds; and (3) estimates of x-ray absorptions and distances to the clouds, using optical/UV/EUV extinction and absorption line observations of foreground and background stars of known distances. In a pilot project (Wang & Yu, 1995, AJ, 109, 698), we have found that anti-correlation between infrared emission from cirrus clouds and background X-ray intensity is present in all five fields we have examined, indicating that a considerable number of degree-size, X-ray-absorbing gas clouds are embedded in the X-ray-emitting medium around the Sun.

I will present new results from this study. In particular, I will report a measurement of the temperature, pressure, and line-of-sight distribution of the hot gas. Our goal is to construct a 3-D picture of the hot gas in the solar neighborhood and to clarify the origin of the gas.

15.07

The Chemodynamics of Superbubbles in Dwarf Galaxies

R. A. Benjamin and E. D. Skillman (U. Minnesota)

We present the results of a high resolution 2-D hydrodynamical model designed to study the chemical and dynamical evolution of dwarf irregular galaxies. We examine the effects of the energy and mass injection of supernovae produced by a stellar OB associations, modelling the interstellar medium of dwarf galaxies and tracking the evolution of the resultant "super-bubble" of hot interstellar gas. Two unique features of our code are the ability to track the cosmic chemical abundances as a function of time and position in a galaxy, and the use of appropriate cooling functions for the low metallicity ambient ISM ($Z = 0.1 Z_\odot$) and the metal-enriched stellar ejecta. We demonstrate what galactic parameters are necessary for such bubbles to "blow-out" of the gaseous component of galaxy and parameterize this galactic metal-loss rate as a function of these parameters. This metal loss is potentially important in producing the observed mass-metallicity relation in dwarf irregular galaxies. In addition we couple the hydrodynamical calculations with routines to calculate the spectral emission diagnostics of these superbubbles, generating synthetic X-ray emission maps and spectra for comparison with observations.

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